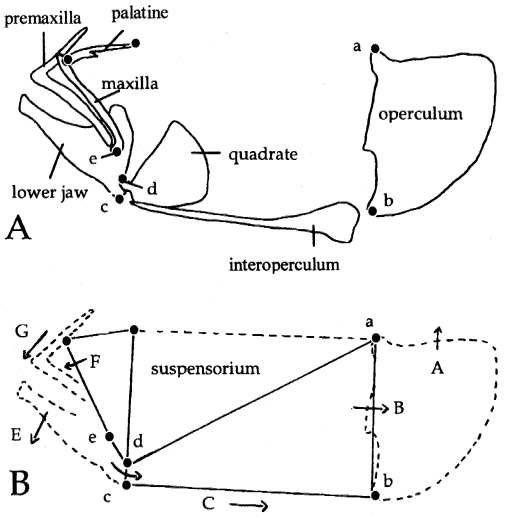

Fig. 1. (A) Landmarks corresponding to four-bar linkage model of *Gasterosteus aculeatus* jaw mechanics. (B) Four-bar linkage mechanics of the skull of *Gasterosteus aculeatus*. The levator operculi muscle exerts a force (A) on the operculum causing it to pivot dorsally about point (a). This rotation exerts a caudad directed force (B) on the interoperculum (b). This transfers a force (C) to point (c) causing it to move caudally relative to (d), which depresses the lower jaw (force E). Depression of the lower jaw pulls point (e) which rotates the maxilla in the direction of force (F). The premaxilla is simply pulled along by the maxilla and is protruded (G).

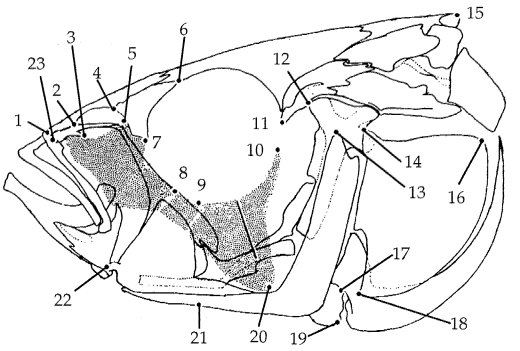

Fig. 2. Positions of landmarks used in morphometric analyses of threespine stickleback skull morphology. Figure reproduced with modification from Bowne (1994). (See Table 1 for descriptions.)

uniform and nonuniform components of shape for each specimen (Bookstein, 1989, 1991). The thin-plate spline utilizes variation in the parameters of an interpolating function to express variation among specimens. Specifically, the shape of a reference configuration of landmarks is used to generate this interpolating function, which is then decomposed into a series of geometrically orthogonal elements called principal warps (Bookstein, 1989). The principal warps are multidimensional shape axes that represent a decomposition of the possible shape deformations that could occur starting from the reference configuration. By projecting each specimen onto these shape axes, the deviations in shape of that specimen from the reference configuration is expressed as a set of shape variables, or partial-warp scores, which represent the deformation of the reference configuration into that particular specimen (Bookstein, 1989; Rohlf, 1993). Because six degrees of freedom are lost in the analysis of two-dimensional data (two for translation, one for rotation, one for scale, and two for the uniform components of shape), there were 40 ($2p$-6) partial-warp scores

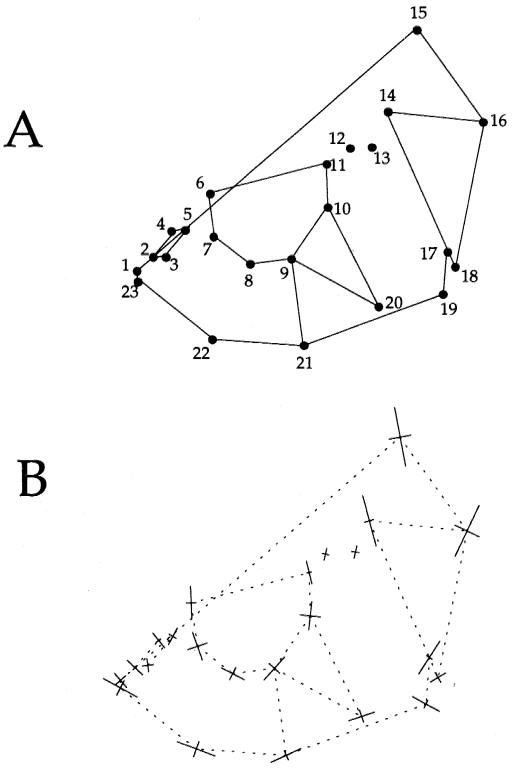

Fig. 3. (A) Outline representation of stickleback skull obtained by connecting the 23 landmarks to selected other landmarks used in this study. (B) Generalized least squares (Procrustes) superimposition of 400 specimens after translation, rotation, and scaling each specimen. Variation present at each landmark is represented by principal axes, and the outline formed by connecting the mean coordinates of each landmark represents the reference configuration.